Microstrip Diplexer Design Using Three EBG

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Abstract— A novel diplexer design by combining of three electromagnetic band gap (EBG) structures is presented in this paper. The diplexer is constructed by combining an EBG at the input port with two different EBG at the output ports. The proposed diplexer is configured with filter in each arm to reject unwanted signals. The first or the second bandpass falls into the stop-band and can be suppressed by EBG structures as well as band pass is controlled directly by EBG structure. Further the EBG structure demonstrates a good performance to improve the mutual coupling. Practical applications of EBG structure usually have difficulty in accommodating its physical size, because the period of EBG lattices has to be a half-waveleng that the band-gap frequency. The proposed design has been implemented in a 25 mil thick Rogers RO301 0substrate. It provides a new idea for designing more efficient structures for microwave circuit applications, such as filters, diplexer, and other passive circuits. This research is only the first step for the feasibility study of the diplexer design by using EBG technology, which can be modified to the other desired frequency bands. The proposed diplexer is simple to fabricate, as it is designed using microstrip technology, and presents compact dimensions, making use of a low number of elements. The excellent simulation results of transmission, reflexion and isolation magnitudes are an excellent starting point to develop a robust design methodology.

1. INTRODUCTION

EBG structures exhibit unique characteristics to guide, filter or collimate electromagnetic waves and have attracted a lot of interest from the research community in recent years. EBG structure is a periodically loaded structure with reactive elements, whose cells provide a wide stop-band [1]. Due to this, they have been widely applied in designs of planar filters to optimize their performance and to minimize their circuits. These periodic structures were originally proposed at optical frequencies and are known as a photonic bandgap (PBG) structure or photonic crystal (PC) [2]. Recently, there has been considerable research effort in EBG structures because the interaction of electromagnetic waves with them generated phenomena like metasurfaces and enhanced transmission [3], and other advances in filters design [4].

It has been designed a mainly EBG with two frequency bands, that will be used to design a diplexer. The diplexer is one of the key components in a transceiver which greatly affects system performance that it also a current research due to theneed to improve its design features as high isolation, low insertion loss and high selectivity [5, 6]. In [7] has been designed a diplexer based on complementary split-ring resonators (CSRRs) with comparable characteristics to our diplexer, but on the other hand, a complicated fabrication with metalized vias. In [5] is designed a complicated fabricated diplexer with metallic vias to the ground and lower isolation values.

EBG structures have been designed in a RO3010 25 mil Rogers substrate characterized by a loss tangent $\delta = 0.0022$ and $\varepsilon_r = 10.2$, and simulations have been done using ADS 2013.06 simulation software in Agilent.

2. EBG STRUCTURES

EBG structures are relatively simple periodic structures, and can be analysed as infinite periodic structures. Conceptually, EBG can be defined as a loaded line, namely, each unit cell of the line consists of a length d of transmission line with a shunt susceptance across the midpoint of the line. Accordingly, the unit cell that defines a section can be defined as:

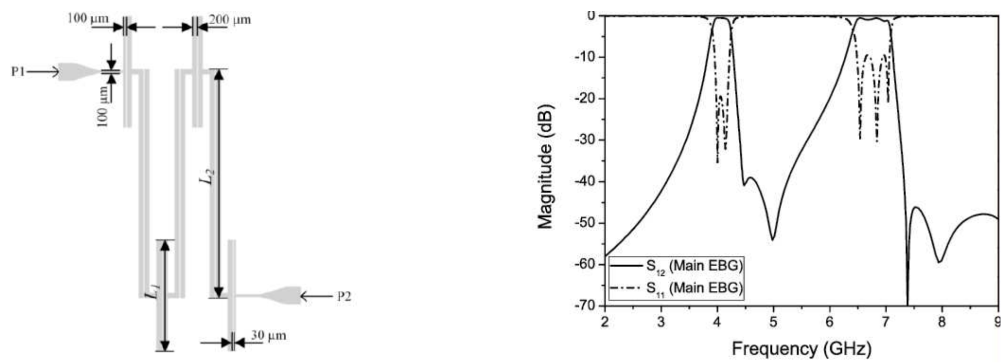
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\frac{\theta}{2} & j\sin\frac{\theta}{2} \\ j\sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix} \begin{bmatrix} 1 & 0 \\ jb & 1 \end{bmatrix} \begin{bmatrix} \cos\frac{\theta}{2} & j\sin\frac{\theta}{2} \\ j\sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix} \tag{1}$$

Developing the unit cell matrix (1) we obtain the Equation (2) for reciprocal networks. If Equation (3) is defined, we can obtain a pass-band filter (if $\alpha = 0$, $\beta \neq 0$) and stop-band filter (if $\alpha \neq 0$, $\beta = 0$). Therefore, for the matrix that defines EBG loads have been designed two EBG at the output ports that suppress the desired frequency band.

$$\cosh\gamma d = \frac{A+D}{2} = \cos\theta - \frac{b}{2}\sin\theta \tag{2}$$

$$\gamma = \alpha + j\beta \tag{3}$$

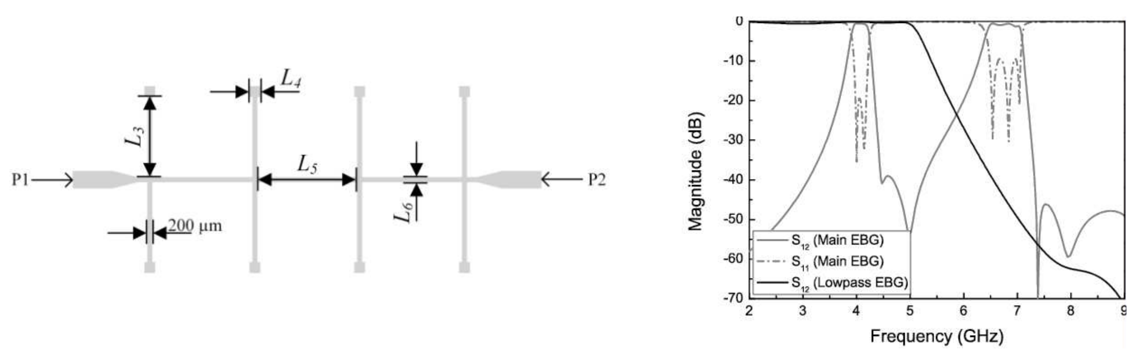
Figure 1 shows the main EBG layout, in which the dark grey parts denote conductor strip and two sides are connected with a $50\,\Omega$ microstrip line, and simulated-S parameters in which we can observe two clear frequency bands at 4 and 6.8 GHz. The losses in the band-pass oscillate between -0.2 dB and -1.2 dB, being compatible with the typical values of the ohmic losses in microstrip filters. Return losses are below to -10 dB, also necessary to filters design. L_1 and L_2 can be modified to vary central frequency of each frequency bands, thus providing great flexibility to diplexers design. A line to basic cell coupling has been incorporated to maximize coupling between microstrip line and EBG structure.



(a) (b)

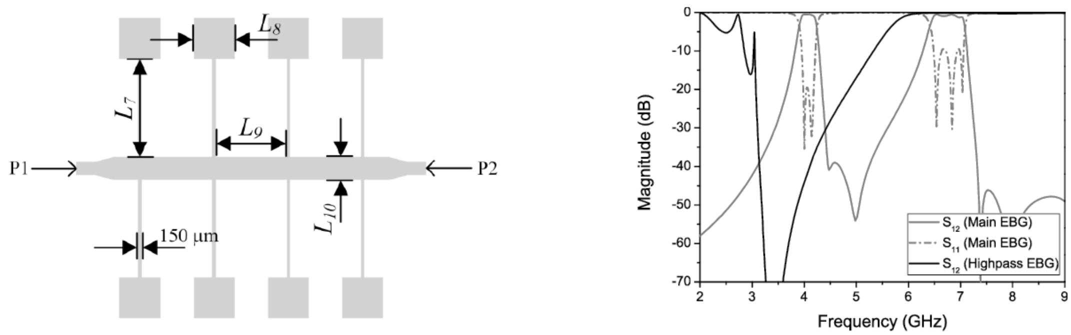
Figure 1: Layout of the proposed main EBG with (a) two frequency bands and (b) simulated S-parameters. $P1$ is the input port, $P2$ is the output port and geometric values correspond to $L_1 = 9$ mm and $L_2 = 4.4$ mm.

Figure 2 shows the layout of the proposed low-pass EBG and S-parameters overlap of main EBG and low-pass EBG that suppress second frequency band at 6.8 GHz. Low-pass EBG has been designed to have the maximum impedance matching ($50\,\Omega$) at first bandat 4 GHz and a top cut-off frequency of 5.1 GHz. Layout of the proposed high-pass EBG and S-parameters superposition of main EBG and high-pass EBG has been shown in Figure 3. In this case, the maximum impedance matching ($50\,\Omega$) has been designed in second band at 6.8 GHz and lower cut-off frequency at 5.7 GHz. In all layouts, the dark grey parts denote conductor strip and two sides are connected with a $50\,\Omega$ microstrip line.



(a) (b)

Figure 2: Layout of (a) the proposed low-pass EBG and (b) simulated S-parameters. $P1$ is the input port, $P2$ is the output port and geometric values correspond to $L_3 = 9$ mm, $L_4 = 4.4$ mm, $L_5 = 4.4$ mm and $L_6 = 200\,\mu$m.



(a) (b)

Figure 3: Layout of (a) the proposed high-pass EBG and (b) simulated S-parameters. $P1$ is the input port, $P2$ is the output port and geometric values correspond to $L_7 = 4.2\,\mathrm{mm}$, $L_8 = 1.73\,\mathrm{mm}$, $L_9 = 4\,\mathrm{mm}$ and $L_{10} = 1\,\mathrm{mm}$.

To EBG filters design, L_3, L_4, L_5, L_7, L_8 and L_9 provide the value of susceptance for which we define the cut-off frequencies, while L_6 and L_{10} allow maximum impedance matching ($50\,\Omega$) at the first or the second band as required. Therefore, this design has great flexibility because we can choose the desired bands and designing EBG filters for each case. Starting and ending frequencies of the band gap generated by both EBG filters are approximated by:

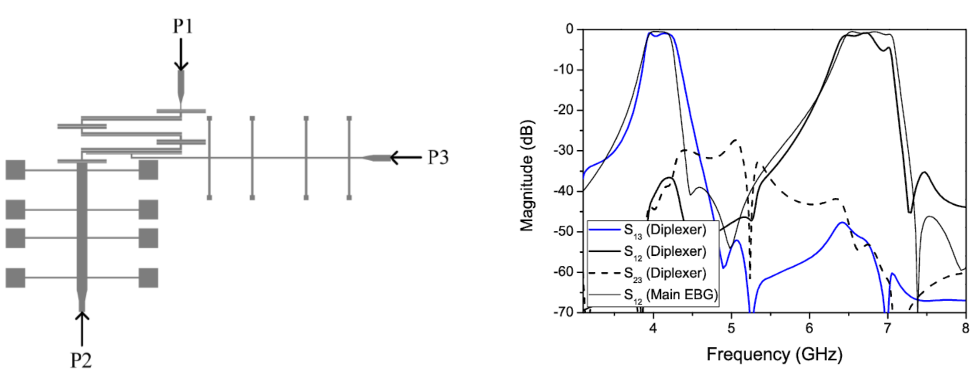
$$f_{low} = \frac{1}{\pi\sqrt{C_p\left(L_p + L_b\right)}} \tag{4}$$

$$f_{high} = \frac{c_0}{2b\sqrt{\varepsilon_r}} \tag{5}$$

where C_p and L_p are inductance and capacitance values for equivalent LC series circuit of squares and L_b inductance of bridges, c_0 is speed of light, b is L_5 or L_9, and ε_r is relative epsilon from substrate.

3. PROPOSED DESIGN

Figure 4 shows the layout of the diplexer prototype and S-parameters of transmission, reflexion and isolation magnitudes. At 4 GHz, port 3 is through, $S_{13} = -1.1\,\mathrm{dB}$, while port 2 is isolated, $S_{12} = -40.1\,\mathrm{dB}$. At 6.8 GHz, port 2 is through, $S_{12} = -0.8\,\mathrm{dB}$, while port 3 is isolated, $S_{13} = -54.4\,\mathrm{dB}$. At 4 and 6.8 GHz $S_{23} = -44.9\,\mathrm{dB}$ and $-54.7\,\mathrm{dB}$ respectively. Its size is about $0.26\lambda_g \times 0.42\lambda_g \times 0.008\lambda_g$, where λ_g is the wavelength of the first channel center frequency. Two channels have a fractional bandwidth (FBW) of 8% approximately.



(a) (b)

Figure 4: Layout of (a) the diplexer prototype and (b) simulated S-parameters. $P1$ is the input port, $P2$ is the output channel 1 and $P3$ is the output channel 3.

Table 1 shows the performance comparison of the proposed diplexer simulated results in this work with other diplexers. The suppression of S_{21} or S_{31} is much wider than those of previously reported diplexers, and isolation and size are quite similar. Moreover, diplexer of this work has an

Table 1: Comparison between the proposed diplexer and the references.

Ref.	3D Size	$\lvert S_{21}\rvert$or $\lvert S_{31}\rvert$(Insertion loss)		$\lvert S_{21}\rvert$or $\lvert S_{31}\rvert$(Suppression)		$\lvert S_{32}\rvert$
		Channel 1	Channel 2	Channel 1	Channel 2	(Isolation)
This work	$0.26\lambda_g \times 0.42\lambda_g \times 0.008\lambda_g$	0.2 dB	1.2 dB	40 dB	54 dB	30 dB
[5]	$0.26\lambda_g \times 0.45\lambda_g \times 0.0016\lambda_g$	1.4 dB	1.6 dB	39 dB	40 dB	25 dB
[6]	$0.58\lambda_g \times 0.40\lambda_g \times 0.017\lambda_g$	1.9 dB	2.0 dB	27 dB	23 dB	26 dB
[7]	$0.27\lambda_g \times 0.23\lambda_g \times 0.008\lambda_g$	1.6 dB	2.3 dB	43 dB	28 dB	32 dB

easy fabrication without vias to the ground or without etched ground plane. Due to the positive results of the simulation with respect to previous works, work is in progress to improve compaction of the three EBG to obtain similar transmission results to main EBG and measure fabricated results.

4. CONCLUSION

This paper designs a planar diplexer based on three EBG. This new configuration of diplexer shows advantages of low loss, high isolation, easy fabrication, compact size and design flexibility. The diplexer performance, in terms of the simulated insertion loss (approximately 0.2 dB and 1.2 dB for the two channels), and isolation (better than 40 dB), is good. Therefore, the proposed diplexer is desirable for microwave transceiver systems.

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